Uranium Isotope Comminution Ages: A New Way to Study Sedimentation Processes

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RESEARCH OBJECTIVES

Erosion is a fundamental Earth process, in which rocks are broken down by mechanical and chemical means into small fragments and transported by streams, glaciers, winds, and ocean currents, ultimately to accumulate as sediment on the ocean floor, or in lakes, or river floodplains. The time that it takes for individual particles to travel from the their source to the site of deposition can be roughly estimated using material balance calculations, but there has not been a means to measure it. In the course of research using uranium (U) isotopes to measure weathering rates of soils and sediments, we have discovered a means to measure the transport times of sedimentary particles. This method now allows us to evaluate how transport time changes with climate, tectonic activity, and other factors, and may also be useful for dating nonmarine sediments and atmospheric dust.

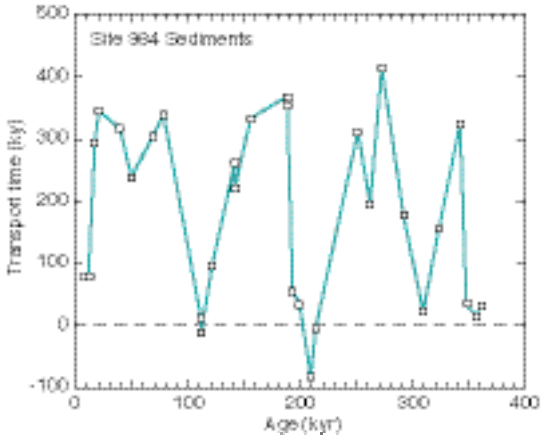

Figure 1. Calculated transport time (from sediment source to site of deposition) for fine-grained silicate fraction of sediment from ODP Site 984 in the North Atlantic. During interglacial periods, transport is rapid; during glacial times, it is much slower. The relationship between glaciation and transport time is less simple for age greater than 250 thousand years. Measured $^{234}U/^{238}U$ activity ratios vary from 0.83 to 0.97.

APPROACH

The basis for the method is that the $^{234}U/^{238}U$ ratio of sedimentary particulates of diameter less than about 50 μm measures the age of the particle. The "clock" is provided by the disruption of the normal ^{238}U decay series resulting from the loss of the ^{238}U decay product, ^{234}Th, by recoil during alpha decay of ^{238}U. When a small mineral grain is produced by erosion, it begins to leak ^{234}Th to its surroundings, and its $^{234}U/^{238}U$ ratio starts to decrease. To reach the steady-state $^{234}U/^{238}U$ ratio appropriate to its size requires about 1 million years, during which time the $^{234}U/^{238}U$ is measuring the time since the small grain was produced, which we refer to as the "comminution age." If the time between production of the small grains and deposition on the sea floor is relatively short (10,000 years or less), then the particles will still have $^{234}U/^{238}U$ activity ratios that are close to 1.0. If the time scale for transport to the ultimate site of deposition is much longer (≥100,000 years), then the grains will be deposited with a $^{234}U/^{238}U$ activity ratio significantly less than 1.0. Typical depletions in ^{234}U in fine-grained sediments are 5% to 30%, and this depletion can be measured to ±0.1% using multicollector inductively coupled plasma mass spectroscopy (ICPMS).

ACCOMPLISHMENTS

Data have been collected for a clastic deep sea sedimentary sequence from Ocean Drilling Program (ODP) Site 984A in the North Atlantic. The sediments contain primary marine carbonate and authigenic components, and hence were first leached with hydrochloric acid. The data show cyclic variations in the measured $^{234}U/^{238}U$ activity ratio, indicating that transport time for sediment to this site has varied considerably with time (Figure 1). Comparison with O isotope records and Nd and Sr isotopes shows that the transport time variations correlate with glacial cycles, and that the source of the sediment also shifts as the transport time changes. During interglacials, the sediment is dominated by material derived from Iceland and transported rapidly to the site of deposition. During glacials, the sediment is from a continental source and has a long transport time, probably because Iceland is surrounded by sea ice and the deposition is either aeolian or redistributed from exposed continental shelves.

SIGNIFICANCE OF FINDINGS

The U isotope comminution age model may open up new ways of understanding the movement of sediment and dust on the Earth. The method may be useful for dating glacial moraine, loess, lake and river sediments, and for determining the sources of atmospheric mineral dust.

RELATED PUBLICATION

Maher, K., D.J. DePaolo, and J.C. Lin, Rates of diagenetic reactions in deep-sea sediment: In-situ measurement using $^{234}U/^{238}U$ of pore fluids. Geochimica et Cosmochimica Acta, 68 (22), 4629–4648, 2004. Berkeley Lab Report LBNL-56681.

ACKNOWLEDGMENTS

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